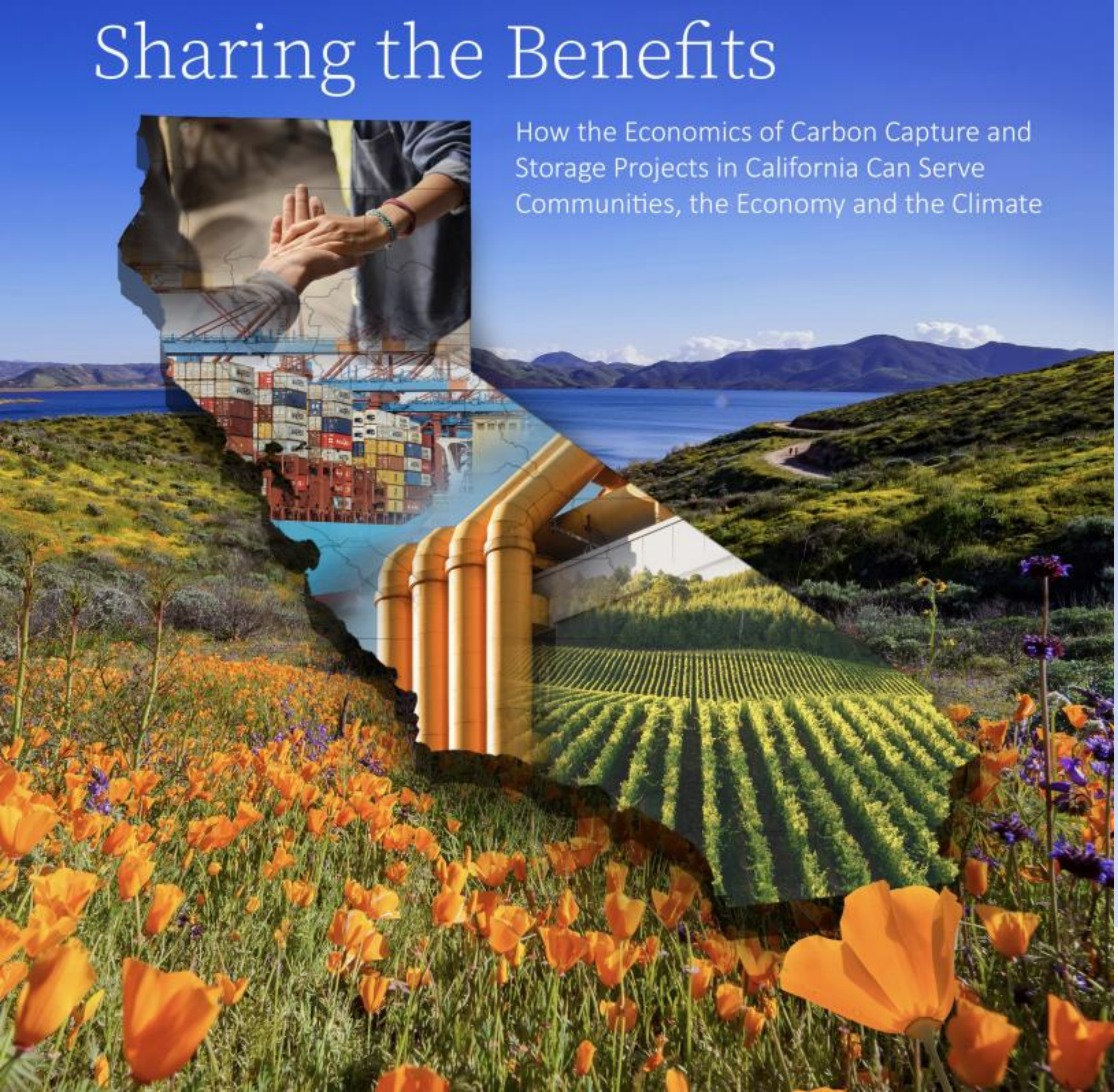

Economics of CCS in California

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Backdrop and Context

- **CCS and CDR necessary to meet California's climate goals**
- **Recent legislation (SB 905) and upcoming rulemakings**
  - Carbon Capture, Removal, Utilization, and Storage Program (CARB)
  - Standards for fair and reasonable compensation for owners of surface, mineral, and subsurface rights (CNRA)
- **Considerable project activity due to federal and state incentives**
- **Landowners and farmers considering geologic CO_2 storage**

The report is NOT:

- A cost lookup table!
- Condoning any individual project or project type

Presentation Outline

- Key findings and results
- Capture cost overview
- Transportation cost overview
- Storage cost overview
- Case studies
- Conclusions and implications for policy makers, community members, landowners and other stakeholders

Key Findings

- Incentives (e.g., 45Q, LCFS) are essential for project viability
- Projects eligible for both 45Q and LCFS hold meaningful potential for local benefits
- Projects not eligible for LCFS face challenging economics
- Project viability and benefit potential depend heavily on:
  - CO_2 flue gas stream concentration
  - The ability to use CO_2 pipelines or marine transport
  - Proximity to good geologic storage
- Trucking and railing CO_2 are pipeline alternatives
  - Often at a sizeable cost
  - Still within reasonable policy support ranges

Key Findings cont'd.

- **Project specifics and local factors can have a distinct effect on costs:**
  - Plant location, age and configuration
  - Access to low-cost energy
  - Challenging pipeline routings
  - Supply-chain constraints and inflation
- **Several project classes of projects are viable now and offer a potentially sizeable up-side (double $/t$CO_2$ digits) for landowners and host communities**
- **Broader project acceptance and proliferation would result from a compensation structure that grows or shrinks commensurate with actual project revenues**

	UNDER LOW END CAPTURE COSTS		UNDER HIGH END CAPTURE COSTS	
Case Study	Project Surplus ($/t$CO_2$)	Project Deficit ($/t$CO_2$)	Project Surplus ($/t$CO_2$)	Project Deficit ($/t$CO_2$)
Ethanol	114		93	
Refinery (FCC)	87		33	
Refinery (SMR)	90		17	
NGCC		-27		-104
Cement		-155		-224

	SENSITIVITY	UNDER LOW/HIGH END CAPTURE COSTS	
CASE STUDY		Project Surplus ($/t$CO_2$)	Project Deficit ($/t$CO_2$)
Ethanol	Use pipeline instead of barge	(93→) **106**	
Refinery (SMR) #1	Use tanker trucks instead of pipeline	(17→)	**-45**
Refinery (SMR) #2	Use barges instead of pipeline	(90→) 76	
Refinery (SMR) #3	Increase incentive period to 20 years	(17→) **24**	
Refinery (SMR) #4	Increase LCFS credit price to $175/t$CO_2$	(17→) **57**	
Refinery (SMR) #5	Increase target rate of return to 15%	(17→)	**-23**
NGCC	Increase incentive period to 20 years		(-104→) **-97**
Cement	Use pipeline instead of rail		(-224→) **-84**

Incentives and Revenue Sources

(Excluding project outputs, commodities and products)

Federal 45Q Tax Credit

- \$50 to \$85/tCO_2 for saline storage of industrial CO_2
- \$50 to \$180/tCO_2 for direct air capture
- 12 years
- Inflation adjusted
- Commence construction before Jan 1, 2033
- Transferable
- Direct payment option

Low Carbon Fuel Standard

- For projects that lower California's transportation fuels carbon intensity
- Variable price: ~\$60-200/tCO_2 in past 5 years
- Credit price expected to rise in response to planned tightening of LCFS targets
- Projects must comply with CARB CCS Protocol (2018)

Capture Cost Overview

APPLICATION	ASSUMED ANNUAL EMISSION RATE (tCO_2/y)	COST RANGE ($/$tCO_2$ CAPTURED)	SOURCES
Cement Plants	1,000,000	55-120	GPI ($55-69), NETL ($64), IEA ($60-120), industry survey (81), NPC ($64-95)
Refinery FCCs	1,000,000	55-150	GPI ($55-71), industry survey ($100), ($97-150 as-suming only 374,000 tCO2/y)
Refinery SMRs	1,000,000	50-111	IEA ($50-80), industry survey ($111), NPC ($61-88)
NGCCs	1,000,000	76-140	GPI ($76-104), Rubin/Herzog ($74 avg), industry survey ($132), NPC ($93-140)
Ethanol Plants	500,000	16-35	GPI ($16-19), NETL ($17-37), IEA ($25-35), industry survey ($30), NPC ($24-34)

- Capture costs derived from literature and industry surveys
- Cost ranges based on amine absorption technology
- Costs generally higher for more dilute streams (e.g., NGCCs) and lower for highly concentrated streams (e.g., ethanol)

Transportation Cost Overview

- **Pipeline**
  - Pipeline cost estimates generated using NETL Transportation Cost Model
  - Pipeline is by far the most economically favorable mode of transportation
  - Generic 60-mile pipeline transporting ~1MT/yr has a CapEx of ~$1 million per mile and an OpEx of ~$1/ton
- **Rail**
  - Rail cost estimates based on recent analysis by Corey Myers and Wenqin Li at LLNL
  - Rail transportation can be feasible where no other options exist, but at a significant cost
  - Rail transportation costs start slightly above $100/ton, regardless of whether tankers or intermodals are used

Transportation Cost Overview cont'd.

- **Truck**
  - Truck cost estimates based on recent analysis by Corey Myers and Wenqin Li at LLNL
  - Truck transportation can be feasible over shorter distances (i.e., shorter than 100 miles)
  - Costs for intermodals start around $50/ton for distances shorter than 100 miles
- **Barge**
  - Cost estimates for barge solely from industry survey of market participants due to limited published literature
  - Can be feasible and cost-effective where suitable waterways are available
  - ~$25 million CapEx for each barge, OpEx ~$5-7/ton depending on degree of utilization of each barge

Storage Cost Overview

- **Storage cost estimates generated using NETL's Saline Storage Cost Model**

- **Geologic inputs gathered from WestCARB for three indicative storage locations:**
  - Near **Stockton** (Southern Sacramento Basin)
  - Near **Modesto** (Northern San Joaquin Basin)
  - In **Kern County** (Southern San Joaquin Basin)

- **For a typical project injecting 1 MT/year across 3 injection wells over 12 years:**
  - CapEx just under ~$100m
  - OpEx ~$8/ton
  - Acquisition of 3D seismic for characterization and periodic surveys for monitoring plume constitute significant portion of total cost (~20-30%)
  - Modeled costs are higher than DOE's ~$7-13/ton estimates

Case Studies – Purpose & General Assumptions

Cost estimates were applied to indicative project case studies around California to demonstrate the effect of various factors on project costs and economics.

- **A simple, conservative cash-flow calculation was used:**
  - Capital outlay over first 3 years of project, revenues accruing thereafter
  - A 45Q window of 12 years, 12-year project operation lifetime
  - LCFS credit price of \$125/tCO_2
  - Annual insurance expenditure equal to 3% of revenues
  - Target cash-on-cash RoR of 8%
  - Numbers presented are pre-tax
  - 8% of issued LCFS credits paid into LCFS buffer account
  - 6x terminal enterprise value

Case Study 1: Capture from Corn Ethanol Plant in Stockton

- **Significance:** low-hanging fruit due to very high purity CO_2 stream.
  - 500,000 tCO_2/yr
  - Geologic storage nearby in the Delta (10mi by barge)
  - Eligible for both LCFS and 45Q
- **Sensitivity:** Barge vs pipeline transportation
- **Conclusions:** Low capture costs and both 45Q and LCFS eligibility makes ethanol CCS comfortably economical.
- Project surpluses range from **$93 to 114/$tCO_2$**.

Case Study 2: Capture from Refinery SMR and FCC in Bay Area

- **Significance:** 5 refineries in Bay Area, major CO_2 sources. SMRs, FCCs emit high-concentration CO_2.
  - 1,000,000 tCO_2/yr
  - Geologic storage in the Delta (60mi by pipeline)
  - Eligible for both LCFS and 45Q
- **Sensitivities:** pipeline vs barge vs tanker truck; longer incentive period; higher LCFS prices; higher rate of return.
- **Conclusions:** Such high-concentration refinery components good CCS targets, likely economical with sizeable margins for local benefits.
- Projects surpluses range from **\$17 to 90/tCO_2**.

Case Study 3: Capture from Natural Gas Combined Cycle Power Plant in Tracy

- **Significance:** NGCCs common in CA. Under high renewables, some plants still needed for dispatchable/baseload power.
  - 1,000,000 tCO2/yr
  - Storage near Modesto (35mi by pipeline)
  - Only eligible for 45Q
- **Sensitivity:** Longer 45Q period (20 years vs. 12)
- **Conclusion:** Challenging economics: dilute CO_2 concentration, no incentives beyond 45Q.
- Viability will depend on future policy developments.
- Project deficits range from **-$104 to -$27/tCO_2**.

Case Study 4: Capture from Cement Plant in Mojave/Tehachapi Area

- **Significance:** CA one of largest U.S. cement produces. 7 operating plants emit ~10 million tCO_2/yr. CCS is one of few means to reduce emissions.
  - 1,000,000 tCO_2/yr
  - Geologic storage in Kern County (60mi by rail)
  - Only eligible for 45Q
- **Sensitivity:** Pipeline vs. rail transportation
- **Conclusions:** Challenging economics due to lack of incentives beyond 45Q. Viability will depend on future policy developments.
- Project deficits range from **-$224 to -$155/tCO_2**.

Key Findings

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Implications

- **For policy makers**
  - Incentive programs work!
  - Coverage and eligibility is not as broad across sectors and project types as it needs to be
  - Successes need to be replicated
- **For developers**
  - Many of the pieces that have traditionally been lacking are now in place
  - Time of opportunity: CCS/CDR going from niche towards mainstream
  - New ways to share project benefits equitably pave the way to project proliferation
- **For landowners, community members and local stakeholders**
  - CCS/CDR projects can coexist with existing activities and provide meaningful revenue streams
  - Pore space lease structures and individual project details matter